

# RADARSAT-1 Image Quality Excellence in the Extended Mission

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**Abstract**—RADARSAT-1, the first Canadian SAR remote sensing satellite, continues to provide calibrated data to worldwide users since the start of its routine operation on April 1, 1996, more than 9 years after its launch on November 4, 1995. Both single beams and ScanSAR imagery are still monitored routinely for radiometric calibration performance based on images of the Amazon Rainforest, and for image quality performance using imagery of the RADARSAT-1 Precision Transponders. This paper briefly describes image quality results and recalibration work.

## I. INTRODUCTION

The Canadian Earth observation satellite RADARSAT-1 was launched on November 4, 1995 and declared operational on April 1, 1996. Since commissioning, a number of important milestones have been completed and throughout all these major activities, the RADARSAT-1 system is still meeting and exceeding its performance specification as set out in the RADARSAT System Specification document [1], maintaining SAR image quality. This paper is primarily concerned with the performance of the image quality and the calibration using products generated by the Canadian Data Processing Facility (CDPF). The RADARSAT-1 calibration system is described in [2]. Previous publications on RADARSAT-1 performance describing image quality and calibration performance since launch can be found [3]-[4]-[5]-[6]-[7].

## II. SINGLE BEAM IMAGE QUALITY

The RADARSAT-1 calibration plan is presently in its Maintenance Phase, which started in 1997. In this phase, tracking of beam calibration and image quality parameters are performed on a routine basis. Radiometric Accuracy performance is monitored by measuring deviations of the measured elevation beam pattern when compared to a reference pattern for any given beam, using images of the Amazon Rainforest. Techniques and tools have been developed to measure radiometric deviations both with and without spacecraft roll correction [8]-[9]. Methodology for elevation beam pattern measurement used for RADARSAT-1 beams has been described in detail in [10]. The reference patterns of all calibrated beams are stored in a processing configuration file known as the Payload Parameter File.

It has been observed that beams of various incidence had experienced radiometric fluctuations to a worst case value of 2.2 dB, attributed to changes in their respective elevation beam patterns. Recalibrations were done for those beams and

new Payload Parameter Files containing recalibrated reference patterns were issued to the CDPF processor, as well as to all foreign network station processors. Measurements performed after recalibration indicate improved radiometric accuracy. Fig. 1 shows typical results (measured over the entire incidence angle range and the central 80% part of the swath) as measured for beam W1 since its initial calibration in February 1997.

Changes in the characteristics of several previously calibrated elevation antenna patterns have occurred gradually since 1998, as indicated by calibration measurements, in particular W1, S1, S3 and F4. It was known that Variable Phase Shifters (VPS) would experience significant heating during a normal imaging period of up to 28 minutes, and that VPS's near the centre of the antenna aperture would experience more rapid heating than those near the edges. An experiment was conducted to determine if the change in the elevation antenna pattern was due to the heating or cooling of VPS forming antenna beams. After analysis it was concluded that changes in beam pattern are not due to temperature variations. Long-term performance variability of VPS is probably the cause of these changes [11].

In addition, Image Quality measurement parameters include point target impulse response measures using images of RADARSAT-1 Precision Transponders (RPT) located at four Canadian calibration sites. The main measurements provided by the RPTs are range and azimuth impulse response widths (IRW), range and azimuth peak sidelobe ratios (PSLR), integrated sidelobe ratio (ISLR), and absolute location error (ALE). Fig. 2 through 4 show the IRW results for the three chirp bandwidths used in the RADARSAT-1 SAR system for all single beams, since the beginning of the Maintenance Phase. PSLR, ISLR and ALE measurements, each combined for all three chirps, are shown in Fig. 5, 6 and 7. All measurements for these time-history plots demonstrate a very good stability of the RADARSAT-1 image quality and that it is meeting or exceeding its performance specification during and beyond its design lifetime.

From the beam qualification phase back in 1997 to the present extended mission, the system organisation initially supporting the Data Quality Group have been progressively enhanced for both image analysis and acquisition planning for quality and calibration monitoring. New planning functions to manage the monitoring frequency of each beam over Amazon and RPT sites were added that also help balance the number of images taken in ascending and descending orbital passes. Various refinements were also brought to the image analyses,

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i.e.: monitoring boresight angle of beams, image footprint geographical offsets, signed location error of the image products, etc, along with miscellaneous performance tracking tools, compiling more than 8 years of calibration and image quality analysis results.

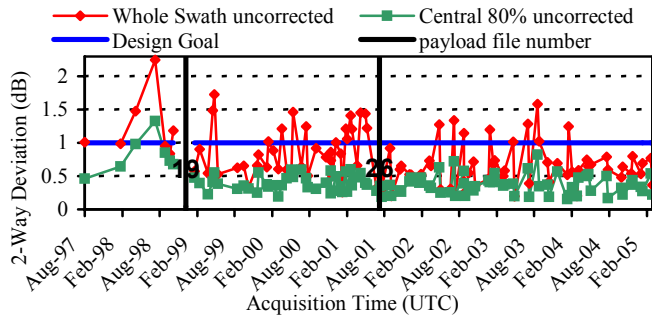


Fig. 1. Beam W1 relative radiometric accuracy performance

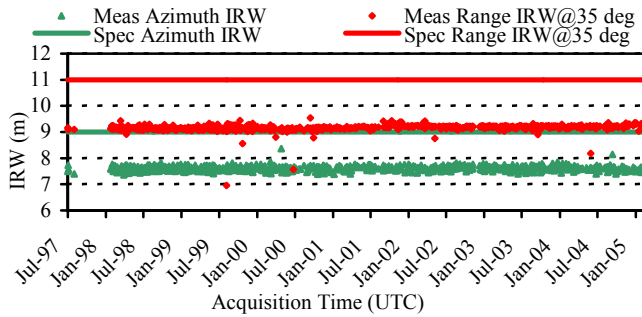


Fig. 2. Impulse Response Width data for chirp 1 beams (BW=30.0 MHz)

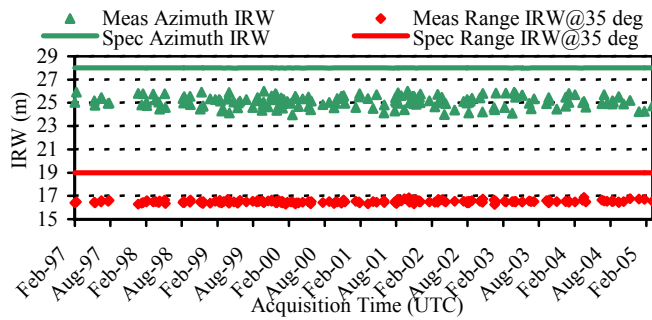


Fig. 3. Impulse Response Width data for chirp 2 beams (BW=17.28 MHz)

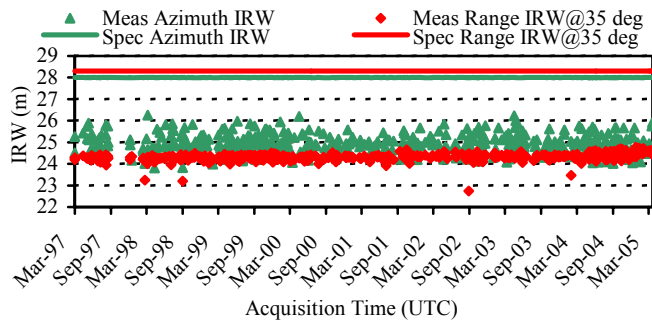


Fig. 4. Impulse Response Width data for chirp 3 beams (BW=11.58 MHz)

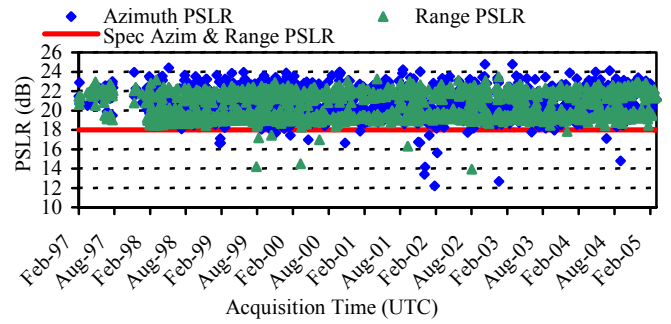


Fig. 5. Peak Sidelobe Ratio for all Beams

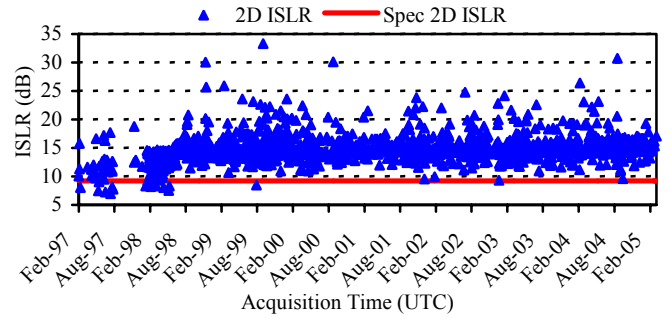


Fig. 6. Integrated Sidelobe Ratio for all Beams

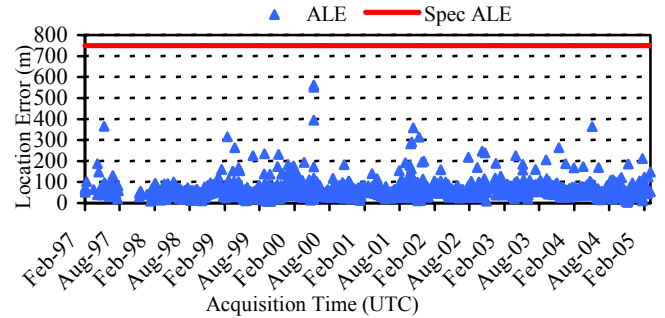


Fig. 7. Absolute Location Error for all Beams

As part of the calibration plan, Amazon-based radiometric monitoring and Transponder-based Image Quality measurements are executed by the Data Quality Group at the Canadian Space Agency (CSA). From the beam qualification phase back in 1997 to the present extended mission, the system organisation initially supporting the Data Quality Group have been progressively enhanced for both image analysis and acquisition planning for quality and calibration monitoring. New planning functions to manage the monitoring frequency of each beam over Amazon and RPT sites were added that also help balance the number of images taken in ascending and descending orbital passes. Various refinements were also brought to the image analyses, i.e.: monitoring boresight angle of beams, image footprint geographical offsets, signed location error of the image products, etc, along with miscellaneous performance tracking tools, compiling more than 8 years of calibration and image quality analysis results.

### III INTERNAL CALIBRATION

RADARSAT-1 incorporates on-board internal calibration for tracking gain variations of the receiver subsystem components: limiter, low noise amplifier, mixer, IF and video circuit. Acquired at transmit pulse times, derived auxiliary telemetry is transmitted to the ground processor together with the radar signal data allowing the processor to compensate for gain variation. Other tracking signals are acquired during pre and post image operation for off-line special processing [2]. In early 1999, a series of annual tests have been initiated to verify the linearity of the internal calibration, covering a dynamic range of more than 40 dB. Repeated in late 2000/early 2001, February 2002 November 2003, and December 2004, the series of tests show very similar results; no trends were detected which would indicate any degradation of the SAR instrument gain [12]

### IV RADARSAT-1 PERFORMANCE IN ADM3 MODE

The RADARSAT-1 Spacecraft Attitude Control System's primary and most accurate method, Attitude Determination Method one (ADM1), uses a sun sensor and a horizon scanner (HS1) for orientation data. An alternate horizon scanner (HS2) severely degraded in performance early in the mission operation. In late October 2000, slightly less than five years after the launch of RADARSAT-1, concerns began to rise of the possibility of failure of HS1. This condition would result in reduced attitude control of the spacecraft with operation of the Sun and magnetometer attitude sensors, known as 'Attitude Determination method 3' (ADM3).

Considerable effort has been expended in 2001 to test and to align the backup ADM3 with the primary ADM1. In pursuing this objective, an experiment was designed towards characterizing attitude performance (in terms of pitch, yaw and roll) by forcing the spacecraft in the ADM3 configuration for a single orbit, then reverting back to the nominal ADM1 configuration (i.e., sun sensor + horizon scanner). Such results could be useful for calibration of the attitude sensors, particularly if the spacecraft is forced into routine operation in ADM3.

Four flight test campaigns have been conducted by RADARSAT-1 Flight Dynamics personnel during the experiment to gather representative data of ADM3 operation, and to test modifications to ADM3 control parameters. These experiments were also conducted to gain a better understanding of impact on processing and image quality when operating the spacecraft in ADM3 mode [13]. A total of 69 images were acquired at different parts of orbit over three planned events and multiple orbits (January 2001, May 2001 and December 2001/January 2002). Though more image re-processing would be expected at CDPF in ADM3 mode due to increased error in estimation of Doppler ambiguity, images were processed successfully during the experiments, with image quality parameters (IRW, PSLR, ISLR) and radiometric accuracy measurements within specification.

From those experiments, an attitude estimation method for spacecraft roll was developed by adapting the existing methodology used for elevation pattern measurement based on Amazon images following a method suggested in [14]. This method involves changing a range-dependent correction factor

used in the final step of the pattern measurement, based on changes in the SAR antenna elevation beam profile in radar imagery of ocean and moderately homogeneous distributed targets, as described in [13]. In the proposed method, the scattering law for other target classes is modeled and residual shape anomalies are attributed to spacecraft roll. Roll attitude is achieved by performing the following steps:

- measure  $\gamma^\circ$  (backscattering strength) pattern from the processed image
- derive the  $\beta^\circ$  (radar brightness) over the same incidence angle range
- replace the  $\beta^\circ$  Look-up Table (LUT) used for Amazon region with the modified  $\beta^\circ$  LUT
- with the modified  $\beta^\circ$  LUT in place, measure the one-way beam pattern. Roll is obtained by making the difference between the calibrated and test boresight angles.

The radar brightness parameter  $\beta^\circ$  is related to  $\gamma^\circ$  via the following equation, where  $\theta$  is the incidence angle, in radians:

$$\gamma^\circ = \beta^\circ \tan \theta \quad (1)$$

A second attitude estimation method has also emerged using SAR imaging as a basis for independently measuring spacecraft attitude errors, using measurements of the radar signal Doppler data. The series of ADM3 flight tests has allowed these methods to be validated by comparison with Attitude Control System ADM1 results. Doppler is however very insensitive to roll errors, which is why roll error was measured using the elevation beam correlation method explained above.

### V. SCANSAR IMAGE QUALITY

Effective February 1, 1999, all ScanSAR images generated by the CDPF are radiometrically calibrated. A major upgrade of the ScanSAR processor in CDPF was done in 2002. This upgrade provides remarkable improvements in image quality, with elimination of processing problems such as scalloping, location error, visibility of beam boundary and Automatic Gain Control (AGC) saturation error.

Based on a limited set of Amazon Rainforest data, it is found that the worst-case absolute accuracy is  $\pm 1.35$  dB, and relative accuracy is 2.7 dB within any image or between any two images. Users will most typically have imagery with radiometric accuracy of  $\pm 1$  dB or better in absolute level (2 dB or better in relative level). As the reference in calibrating ScanSAR modes, a constant  $\gamma^\circ$  of 6.5 dB was used for the Amazon Rainforest. An example of  $\gamma^\circ$  for a ScanSAR Narrow B (SCNB) image of the Amazon Rainforest is shown in Fig. 8.

After issuance of Payload Parameter File 22, some gain differences have been observed at the boundaries of the constituent beams. This situation was resolved by adjusting relative gains between the single beam components (W1, W2, W3, S5, S6, S7) of all four ScanSAR modes. A new Payload Parameter File (#26) was then issued.

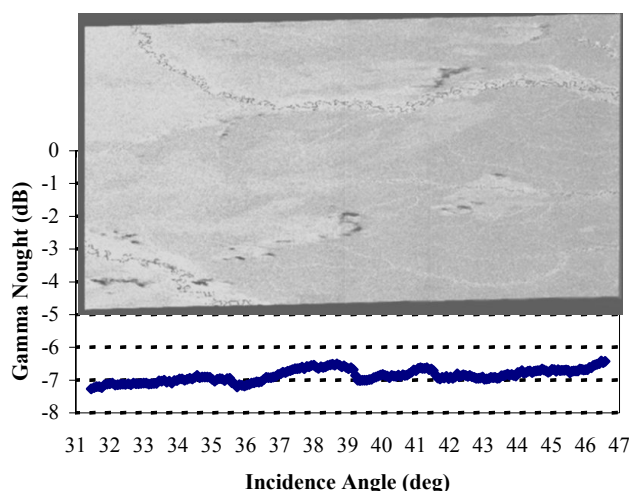


Fig. 8. Gamma nought for SCNB Ascending Pass, 18-Jan-2004

## VI. BOREAL FOREST RADIOMETRIC TEST

Due to aging consideration for the On-Board Recorder (OBR) and since Amazon images used for calibration performance are recorded, alternative sites within Canadian data reception masks are being explored for their ability to support radiometric analyses in case of an OBR failure. Several sites in the Boreal Forest and in the Tundra/Taiga belt in Canada have been selected. From preliminary results, the most homogeneous site in the group, near Hearst, Ontario, was chosen for testing. Radiometric measurements covering the whole range of incidence angle are performed using an elevation pattern measurement method that was developed by adapting the existing methodology for Amazon images analyses [15]. Encouraging results, shown in Fig. 9, demonstrate the concordance between the elevation pattern as obtained from the Boreal Forest and its associated calibration pattern. The peak-to-peak radiometric difference between the two patterns shown is measured for the entire swath and for the central 80% part.

Efforts are ongoing to continue this experiment further, to determine how suitable the Canadian Boreal Forest can be for supporting radiometric analysis. Updated weather data is being adjoined to the analyzed datasets. The compiled results, including snow on the ground (winter), humidity levels (summer) and precipitation conditions at time of acquisition, will assist in evaluating seasonal averages of the regular  $\gamma^0$  measurements (Boreal Forest backscattering) performed on the region.

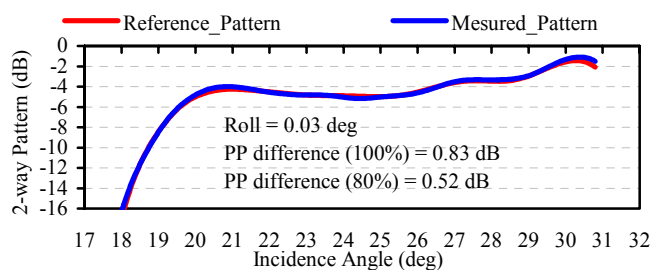


Fig. 9. Pattern Comparison for M0363850 (W1 Asc over Hearst Region on 23 March 2004).

## VII. CONCLUSION

The RADARSAT-1 radiometric performance and image quality have continued to consistently excel from the early Maintenance Phase to present, in the fourth year of extended mission. Measured results indicate image quality performance is maintained better than specification. Over the years, various tests and experiments on attitude control, internal calibration and ScanSAR processing have been used to improve the overall SAR system performance. Developed with the RADARSAT-1 program partners, these methodologies for maintaining calibration may prove to also be beneficial for future SAR remote sensing missions, including RADARSAT-2. In the context of the current mission extension of RADARSAT-1, the radiometric experiment over Boreal Forest, as well as the image quality assessment in ADM3, increases the level of confidence in regards to the future of RADARSAT-1 imagery.

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